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New Approaches to the Treatment of Vascular Lesions

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Background and Objective: **The pulsed dye laser was developed based on the concept of selective photothermolysis. By using a wavelength of light well absorbed by the target and pulse duration short enough to spatially confine thermal injury, specific vascular injury could be produced.**
Study Design/Materials and Methods: **Although the pulsed dye laser revolutionized the treatment of port wine stains (PWS) and a variety of other vascular lesions, the ideal thermal relaxation time for the vessels in PWS is actually 1–10 ms, not 450 μs of the original pulsed dye laser machines. These original theoretical calculations recently have been proven correct in a study that used both an animal vessel model and in human PWS.**
Results: **Longer wavelengths of light, within the visible spectrum, penetrate more deeply into the skin and are more suitable for deeper vessels, whereas longer pulse durations are required for larger caliber vessels.**
Conclusion: **A variety of lasers recently have been developed for the treatment of vascular lesions which incorporate these concepts into their design, including pulsed dye lasers at 1.5 ms, a filtered flash-lamp pulsed light source with pulse durations of 1–20 ms, several 532-nm pulsed lasers with pulse durations of 1 ms to as high as 100 ms, long pulsed alexandrite lasers at 755 nm with pulse durations up to 20 ms, pulsed diode lasers in the 800 to 900 nm range, and long pulsed 1064 Nd:YAG sources. Lasers Surg. Med. 26:158–163, 2000.**

Key words: port wine stain; long pulse laser, telangiectasia; leg veins

INTRODUCTION

In the 1970s and early 1980s, the argon laser and other continuous wave and quasicontinuous wave visible light lasers were the treatment of choice for port wine stains (PWS). Results were impressive in most patients; but pink and immature PWS, especially in children were more difficult to lighten than mature red PWS. Not only were they less responsive, the risk of scarring in this group was reported to be as high as 25% [1].

The pulsed dye laser (PDL) was developed based on the concept of selective photothermolysis [2]. By using a wavelength of light well absorbed by the target and pulse duration short enough to spatially confine thermal injury, specific vascular injury could be produced. The PDL revolutionized the treatment of PWS and a variety of other vascular lesions. The PDL was first manufactured to produce visible light at 577 nm, a minor absorption peak of oxyhemoglobin, with a pulse duration of 450 μs. The dye was later modified to produce 585 nm light, slightly "off peak" in an effort to decrease absorption in hemoglobin at the same time as increasing the depth of light penetration in an effort to target deeper vessels [3]. Although results are very good in many cases, PDL treatment of vascular lesions has its limitations. PWS rarely clear completely, multiple treatments are necessary to achieve maximal lightening, purpura lasts 7–14 days after each treatment, and hypertrophic PWS do not consistently respond.

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TABLE 1. Ideal Laser/Light Parameters for Treatment of Vascular Lesions

	Wavelength (nm)	Pulse duration (ms)	Beam diameter (mm)
Diameter of vessels (μm)			
100	580	1	—
300	590	10	—
600 to 1 mm	600	20–100	—
Vessel depth (mm)			
Less than 1	>500	—	Small
Greater than 1	>600	—	Larger

In reviewing the concept of selective photothermolysis by Anderson and Parrish, the mathematical model predicted that the ideal thermal relaxation time for the vessels in PWS is actually 1–10 ms, not 450 μs. These original theoretical calculations recently have been proven correct in a study that used both an animal vessel model and human PWS [4]. Longer wavelengths of light, within the visible spectrum, penetrate more deeply into the skin and are more suitable for deeper vessels, whereas longer pulse durations are required for larger caliber vessels. The ideal parameters for choosing a laser to treat vascular lesions are listed in Table 1.

A variety of lasers recently have been developed for the treatment of vascular lesions, which incorporate these concepts into their design. These include PDL in which the pulse duration has been lengthened more than threefold to 1.5 ms; a filtered broad spectrum flash-lamp pulsed light source with pulse durations of 1–20 ms; several 532 nm pulsed lasers with pulse durations of 1 ms to as high as 100 ms; pulsed alexandrite lasers at 755 nm with pulse durations up to 20 ms, pulsed diode lasers in the 800–900 nm range; and millisecond pulsed 1064 Nd:YAG sources (Table 2).

Preliminary results with these non-PDL devices show that they produce no purpura or considerably less purpura per J/cm^2 than the traditional pulsed dye laser [4,5] that they may be more effective in the treatment of deep and nodular PWS, and that they may require fewer treatments for PWS lightening [6]. They are also useful in the treatment of a variety of vascular lesions that typically do not respond to the pulsed dye laser. These lesions include paranasal fold vessels, blue deep vessels on the face, and some leg veins.

TABLE 2. Lasers and Light Sources for Vascular Lesions in Order of Increasing Wavelength

Laser/light source	Wavelength (nm)	Pulse duration (ms)
Pulsed KTP	532	1–200
Coherent *Versapulse*		
Cynosure *Illustra*		
Iriderm *Diolite*		
Laserscope *Aura* and *Orion*		
Pulsed dye	585	0.450
Candela *SPTL1B*		
Cynosure V		
Long pulsed dye		
Candela *Sclerolase*	585, 590, 595, 600	1.5
Cynosure *LV*, *VLS*		
Long pulsed alexandrite	755	3–20
Candela *GentleLase*		
Cynosure *LPIR*		
ESC/Sharplan *EpiTouch Alex*		
Diodes	800, 810, 930	1–250
Diomed *Laserlite*		
Coherent *Light Sheer*		
Long pulsed Nd:YAG	1064	
Altus *Cool Glide*		10–100
ESC *Vasculight*		2–16
HGM *Veinlase*		50
Laserscope *Orion*		1–50
Pulsed light source	515–1200	2–20
ESC *Photoderm LV*		

"LONG-PULSE" PULSED DYE LASERS

Based on the theory of selective photothermolysis, the predicted pulse duration ideally suited for thermal destruction of vessels the size of leg telangiectasia (0.1–several mm in diameter) is in the 1- to 50-ms domain. Two "long-pulse" dye lasers with 1.5-ms pulse durations (Cynosure, Chelmsford, MA, and Candela, Natick, MA) were developed to treat such vessels (Table 3). Both devices use a rhodamine dye to produce wavelengths of 585 nm, 590, 595, or 600 nm. Although 1.5 ms is still shorter than the ideal pulse duration to treat all but the smallest cutaneous vessels, the longer pulse duration and wavelength improves our ability to treat deeper, larger caliber vessels.

Indeed, PWS appear to clear at least as quickly as when treated with the traditional pulsed dye laser, but with less profound and less long-lasting purpura. Used with a spray coolant and software that allows very high fluences, impressive early results have been seen particularly

TABLE 3. 585- to 600-nm Pulsed Dye Lasers*

Name	Candela SPTL1b, Sclerolase/ Scleroplus	Cynosure PhotoGenica V/LV
Laser type	Flashlamp-excited pulsed dye laser	Flashlamp-excited pulsed dye laser
Pulse duration	450 μs/1.5 ms	300–500 μsec (V), 1.5 ms (LV)
Pulse rate	Single or 1 Hz	Single or 1 Hz
Spot sizes (mm)	2 × 7, 3, 5, 7, 10	3, 5, 7, 10
Maximum fluence	Up to 20 J/cm^2	Up to 20 J/cm^2

*Advantages: clearance of vessels 1.0 mm in diameter, but most effective for vessels 0.5 mm in diameter. Cynosure VLS combines characteristics of both V and LV. Disadvantages: postoperative erythema, purpura, and postoperative pigmentation changes.

in infants with port wine stains and hemangiomas [6]. Facial blood vessels that have not responded readily to the traditional pulsed dye laser are more responsive, including vessels in the paranasal folds and even vessels up to 1 mm in diameter on the cheeks and nose [5]. Treatment of leg veins less than 0.4 mm in diameter also show promise, but the results in treating larger caliber vessels has been disappointing [7,8].

KTP Lasers

Many pulsed KTP lasers are available for treatment of vascular lesions. The 532-nm KTP light was chosen for a variety of reasons, including the fact that 532-nm light is absorbed by hemoglobin as well as 585-nm light, and the penetration depth is almost the same through fair skin. KTP crystals are highly reliable, convenient to work with and easily available to laser manufacturers. Although the mechanism of these devices varies, each produces millisecond domain pulses at 532 nm. The Versapulse (Coherent, Palo Alto, CA) produces a true millisecond domain pulse, whereas other lasers in this category group nanosecond domain Q-switched pulses into millisecond laser pulses, resulting in slightly lower energy output (Aura and Orion, Laserscope, San Jose, CA; Diolite, Iriderm, Mountain View, CA; Illustra, Cynosure, Bedford, MA).

Results of treatment of facial vessels are excellent, and these lasers are technically simple to use and very patient friendly — no purpura and little erythema or edema, which usually lasts for less than 24 hours [9]. The treatment of leg veins by using small spot sizes and pulse durations of 10 ms or less have been mixed [10,11]. Recent results have been more promising by using larger spot sizes (3–5 mm) and pulse duration of 10 to 50 ms at fluences of 14–20 J/cm^2. Bernstein et al. treated 15 patients with leg veins less than 0.75 mm in diameter with a 10-ms pulsed 532-nm laser by using a 3-mm spot with a chill tip for skin cooling and found that over 75% of veins improved or cleared after two treatments at 16 J/cm [12]. Cooling appears to be of significant benefit in protecting the epidermis, thus allowing use of higher, more effective fluences.

Potential limitations of 532-nm light sources are that, although selective absorption of light by hemoglobin is equal to 585 nm, the shorter wavelength penetrates less deeply and is, therefore, less effective for deeper targets. Furthermore, melanin absorption is increased, making this wavelength suboptimal for darker skin types and also increasing the risk of hypopigmentation.

Other Pulsed Lasers

Based on deep penetration of long wavelength visible and near infrared light, and a small peak of hemoglobin absorption in the 800–900 nm range, long-pulsed millisecond-domain alexandrite, diode, and Nd:YAG lasers have been developed to treat moderately deep, larger caliber spider and feeding reticular veins. Characteristics of the available alexandrite lasers are wavelength of 755 nm and pulse durations of 2–20 ms; of the diode lasers, wavelength 800, 810, and 930 nm and pulse duration of 10–250 ms; and of the Nd:YAG lasers, wavelength 1,064 nm, pulse duration up to 100 ms (Tables 4, 5, 6). Although there have been no reports of using these devices to treat PWS or hemangiomas, results indicate that small vessels less than 0.4 mm in diameter, are not very responsive to such long pulse durations but larger caliber vessels respond relatively well [13] (Dierickx C., personal communication, April 1998; Weiss RA, personal communication, August 1999).

Intense Pulsed Light Source

In an effort to maximize efficacy in treating leg veins, a high-intensity pulsed light source (IPLS) was developed in 1993 (PhotoDerm VL, ESC Medical, Inc., Needham, MA) that emits single, double, or triple pulses of broadband light from 515 to 1,200 nm in pulses 2–20 ms in duration (Table 7). The principles behind development of this pulsed, broadband light source are several. Both oxygenated and deoxygenated hemoglobin

TABLE 4. 755-nm Long-Pulse Alexandrite Lasers*

Name	EpiTouch Alex	GentleLase	LPIR and Apogee
Laser type	Solid state, alexandrite	Solid state, alexandrite	Solid state, alexandrite
Pulse duration (ms)	2	3	5, 10, or 20
Pulse rate (Hz)	5 to 10	1	Single and 1
Spot sizes (mm)	5, 7, and 10	8, 10, 12, 15, 18	7, 10, 12.5 and 6 × 10 (optional)
Maximum fluence	1–50 J/cm^2	8 mm, 100 J/cm^2; 10 mm, 60 J/cm^2; 12 mm, 45 J/cm^2; 15 mm, 30 J/cm^2; 18 mm, 20 J/cm^2	7 mm, 50 J/cm^2; 10 mm, 35 J/cm^2
Other features	Rapid repetition rate	Cryogen spray cooling	Cooling tip
Manufacturer	ESC/Sharplan	Candela Corp., Wayland, MA	Cynosure, Inc., Chelmsford, MA

*Advantages: deeper penetration, less melanin absorption, effective for reticular veins, no postoperative purpura. Disadvantages: less effective for vessels 0.5 mm.

TABLE 5. 800-nm Diode Lasers*

Parameter	Featherlite	Light Sheer
Laser type	Gallium arsenide	AlGaAs semiconductor diode
Pulse duration (ms)	50–250	5–30
Pulse rate (Hz)	5	0.5
Spot sizes (mm)	2, 5, 2 × 4	Spot 9 × 9
Maximum fluence	60 W	10–40 J/cm^2
Other features		Chill tip
Manufacturer	Laserlite, Boston, MA	Star Medical Tech, Inc., Pleasanton, CA

*Advantages: deeper penetration, less melanin absorption effective for reticular veins, no postoperative purpura. Disadvantages: less effective for vessels 0.5 mm.

TABLE 6. 1064-nm Long Pulse Nd:YAG Lasers*

Name	Cool Glide	Orion	Vasculight	Veinlase
Laser type	Nd:YAG	Nd:YAG	Nd:YAG	Nd:YAG
Pulse duration (ms)	10 to 100	1–50	14	50
Pulse rate	up to 2 Hz	1–50 Hz		1–25 Hz
Spot sizes (mm)	3	1–4	6	2
Maximum fluence (J/cm^2)	up to 100	1–50	150	100
Other features		Also functions in a Q-Switched mode and at 532 nm	Synchronized double or triple pulses	
Manufacturer	Altus	Laserscope	ESC Medical	HGM

*Advantages: poor absorption in skin permits penetration to target relatively deep vessels. Long pulse durations ideally suited for large caliber vessels. Disadvantages: insufficient data to make conclusions on effectiveness.

absorb at these wavelengths, deeper wavelengths penetrate deeper into skin, increasing the likelihood of damage to deep vessels, and longer pulse durations heat larger caliber vessels slowly and gently, producing uniform heating without vessel rupture.

The IPLS has been reported to be moderately effective in the treatment of PWS and evolving superficial hemangiomas, but we believe that the pulsed dye laser remains the treatment of choice for both these anomalies. Raulin et al. recently reported 70 to 100% clearing of port wine stains in 28 of 40 patients after an average number of treatments of four for pink port wine stains, 1.5 for red ones, and 4.3 for purple PWS [14]. A multicenter study demonstrated IPLS efficacy in the treatment of leg veins ranging from clearing of 90% of vessels <0.2 mm in diameter, to clearing 80% of vessels 0.2–1.0 mm in diameter after multiple treatment sessions [15]. Adverse sequelae included occasional epidermal crusting, hyperpigmentation, and hypopigmentation in 19%, which usually resolved within 4–6 months. Contradictory results recently have been reported by Green who found that leg vein clearance rates were low and the side effect rate unacceptably high [16]. However, several recent studies have reported encouraging results. By increasing the pulse durations up to 10 ms in two consecutive pulses separated by a 20 ms delay with a 570-nm cut-off filter and fluences as high as 70 J/cm^2, response rates of 74% in two treatments with an 8% incidence of

TABLE 7. Noncoherent Pulsed Light Source*

Name	Photoderm VL
Light source	Flashlamp
Wavelength	515–1200 nm
Pulse duration	VL: 2–25 msec
Pulse rate	Single, double, or triple pulses: delay between pulses
Spot sizes	8 × 35 mm and 8 × 15 mm
Energy range	VL: 3–90 J/cm^2
Manufacturer	ESC Medical Systems, Needham, MA

*Advantages: treats vessels up to 2 mm in diameter. Parameters can be individualized for skin type and vessel size. No postoperative purpura. Disadvantages: long, slow learning curve; potential for pigmentary change if used with lower wavelength filters in darker skin. Slow repetition rate (8 seconds between pulses)

temporary hypo- or hyperpigmentation was found (Weiss, R., personal communication, August, 1998) In a study of 120 patients with a variety of vascular lesions, including leg telangiectasia, Schroeter and Neumann demonstrated the versatility of the IPLS [17]. Plethysmography and Doppler ultrasound were performed in all patients with leg veins. Varicose veins were first treated with surgery and sclerotherapy as needed. Eighty-four percent of leg telangiectasia up to 1 mm in diameter cleared 1 month after a single treatment.

Although results of the treatment of vascular lesions with the intense pulsed light source (Photoderm VL) are encouraging, they are far from being easily reproduced and the technique requires a great deal of experience to achieve good results. Unlike pulsed lasers for which only the spot size and fluence can be varied, the intense pulsed light source offers a wide array of choices, including wavelength, fluence, number of pulses, and pulse delay time, and as a result, ideal treatment parameters have been slow to be established and confirmed.

THE ROLE OF COOLING

The concept of cooling the skin in an effort to protect the epidermis during laser treatment of dermal targets was first studied by Gilchrest et al. [18] with the use of ice before argon laser treatment of PWS. There has been a recent resurgence of interest in skin cooling during skin laser therapy in an effort to not only cool and protect the epidermis and to prevent other collateral dermal damage, but also to reduce the discomfort associated with treatment. Although of importance in the treatment of facial PWS and telangiectasia, because high fluences are required to adequately damage leg veins, cooling is especially important in their treatment in an effort to limit unwanted collateral injury. Several approaches have been taken, including water-cooled chambers applied directly to the skin through which the laser beam is directed (e.g., Chess Chamber, Cool Laser Optics; Versapulse chill tip, Coherent; Photoderm chiller, ESC; Dermacool Distributors, LLC, Mabetton, GA), cooling coupling gels, and refrigerated spray cooling devices (e.g., Dynamic cooling device, Candela Corp.). Results suggest that cooling helps to spare epidermal damage and allows the use of higher fluences, thus yielding more damage of the targeted vessels with a greater degree of clearing per treatment [19,20].

SUMMARY

Given the proliferation of new devices for the treatment of vascular lesions over the past few years, we have changed our treatment approach considerably. For PWS, the treatment of choice is now the long-pulsed 1.5-ms PDL for all except nodular or very thick PWS. For these lesions, we first attempt the long-PDL but where this fails, either high-energy long-pulse 532-nm sources or the IPLS is used. We also consider the long-PDL the device of choice for the treatment of hemangiomas. There are less data available regarding the use of the long-pulsed 532-nm sources or the IPLS in the treatment of hemangiomas, but as further experience is reported, these may also play an important role.

Because the long-pulse 532-nm sources and the IPLS are able to treat facial telangiectasia with virtually no purpura, these devices have become the treatment of choice for our patients with facial telangiectasia. The PDL clears more vessels per treatment and covers a much larger area per treatment than the long-pulse 532-nm sources, but even with cooling and with the new elliptical spot size purpura lasts a minimum of 5, but often 7–10, days. There are, however, certain instances for which we find the long-PDL extremely useful. It is effective in treating telangiectasia in the paranasal folds. We find it to be successful even in treating telangiectasia that are resistant to the treatment with the long-pulsed 532-nm sources. Deep bluish vessels, often resistant to pulsed 532-nm sources, often clear with PDL treatment. The PDL is also a more effective treatment for patients who have facial telangiectasia, with diffuse background facial redness. The long-pulsed 532-

nm sources are effective at treating the vessels in these patients, but not as effective as treating the background redness. The IPLS has advantages similar to the long-pulsed 532-nm sources. It does not produce purpura, and it is effective in treating both the telangiectasia and background erythema.

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